Ontological Modeling Approach to Blending Theories for Instructional and Learning Design

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Abstract: This paper proposes a modeling framework for learning and instructional design from the viewpoint of ontological engineering. One of the characteristics of this framework is a theory/paradigm-independent ontology for modeling learning/instruction. This paper discusses how our modeling framework with the theory/paradigm-independent ontology contributes to modeling learning and instruction from a comprehensive viewpoint of various educational theories.

Keywords: Instructional design, Learning design, Ontology, Theory-aware, Design support

Introduction

Sharing and reuse of information about not only resources but also their structure such as design intention have been brought to public attention as recent development of IT standards in the areas of learning, education, and training. Representative specifications include IEEE LTSC Learning Object Metadata (LOM) standard [9] and IMS Learning Design (LD) specification [10]. These bring about global benefits of exchange format for sharing and reuse of information about learning contents.

However, a problem still remains: how to build "good" design for education using the standards. Of course, considerable achievement has been made in instructional and learning sciences. This being said, even though some educational theories (learning, instructional and instructional design theories) prescribe optimal/desirable methods of learning and instruction, many of the theories are not sufficiently articulated for the use of designers. Such theories allow for diverse interpretation and therefore may be difficult to use in practice.

One of the reasons why these problems come up is that the description of educational theories is made in natural language, using different terminology. As Reigeluth points out, although many theories prescribe the same method for the same situation, these are described in different terminology [18]. This leads to a diversity of theories that are all open to interpretation. Even for experts, it is sometimes difficult to appropriately use theories while having a clear understanding of the similarities and differences between them. Consequently, we must first establish a common basis for understanding the theories at a conceptual level, along with organized concepts and vocabulary.

The goal of this study is to build an engineering infrastructure that enables designers to select instructional and learning theories and blend them into an instructional/learning design. This paper thus proposes a modeling framework for learning and instructional design from the view point of ontological engineering [14], based on the results of previous

research in this respect [1][2][16] . In addition, the purpose of this study is not to expose a scientifically valid basis for organizing educational theories nor to reconstruct them on this basis, but rather to find an engineering approximation that allows the building of an engineering infrastructure that enables practitioners to utilize educational theories.

This paper is organized as follows. The next section presents our perspective on modeling of learning and instruction and proposes our resulting modeling framework for them. Section 2 illustrates an example of a model of theoretical knowledge for education based on this modeling framework. Section 3 discusses an application of this framework to design support system for learning scenarios or activities. The final section concludes this paper and states the issues to be examined further.

1. Ontological modeling framework for instructional/learning design

This study adapts the ontological modeling framework of functional design knowledge in the world of manufacturing industry by Kitamura et al. [12] to model educational theories. The main characteristic of this framework is independent conceptualization of what is achieved and how to achieve the change in the target things. The former is organized as ontologies of functionality, and the latter is as ways of function achievement. The function of artifacts (devices) is modeled as hierarchical structure of component functions linked with ways of function achievement. This model is called "function decomposition tree". Kitamura et al. have confirmed the effectiveness of the framework in: (1) affording a better understanding of the functionality of devices, (2) facilitating the sharing of design rationales of devices, (3) supporting the improvement of functionalities, and so on. Although the domain is different from educational knowledge, we believe that it is applicable to the systematization of theoretical knowledge for instructional/learning design.

For the educational domain, we have developed an ontology of learning, instruction and instructional design (L/I/ID) [1][2][16] . This study proposes an ontological modeling framework for education based both on the L/I/ID ontology and Kitamura's framework [8]. It aims at facilitating (1) the sharing of a model of instruction/learning and (2) the application of educational theories appropriately to the modeling. IMS Learning Design (LD) specification [10] has recently focused on the sharing aspect, and we believe that our approach will contribute to make IMS LD specification work with educational theories.

Roughly speaking, the L/I/ID ontology is composed of five major concepts: concepts related to Common, Learning, Instructional and Instructional design worlds and Educational event in the learning and the instructional worlds [8]. This ontology is developed in an effort to model learning and instruction in any paradigm - Behaviorism, Cognitivism and Constructivism -. Ertmer and Newby [6] assert that although each of the paradigms has many unique features, each describes the same phenomena (learning). In a similar line of thought, one of the notable features of this ontology is the conceptualization of relation between learning and instruction. The meaning of an instruction is defined by the change of learner state as achieved or by the intended result of learning. However, instruction is defined independently of the change of learner state. That is because an instructional action may have different effects on the change depending on the context. Independence is the key to allow for a variety of combinations of instructional actions and effects and to compare strategies provided by educational theories.

The Learning/instruction process is modeled based on our ontological modeling framework for education. A unit of learning/instruction is described as I_L event, which is a sub-class of Educational event. An I_L event is defined as a combination of instructional action and change of learner state caused by a learning action. This definition allows to describe the relation between instruction and learning in a learning/instruction process. The
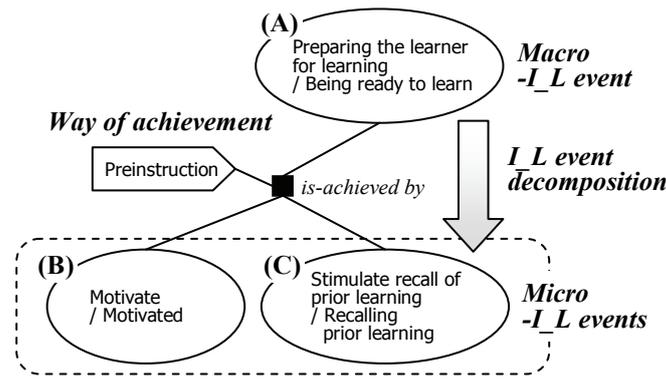
Fig. 1 An example of I_L event decomposition

whole process is modeled as a function decomposition tree. In our framework, this model is a hierarchical structure of I_L event to achieve a certain change of a learner state. Thus, it is called "I_L event decomposition tree". In an I_L event decomposition tree, an upper (macro) I_L event is connected with the lower (micro) ones by way of achievement of change of a learner state (referred to just as "Way" hereafter). For example, consider a situation where an instructor wants a learner to be ready to learn and it is necessary that the learner is motivated into the learning and then that he recalls prior learning. Fig.1 illustrates this case as I_L event decomposition. An oval node represents an I_L event. Fig.1 (A) indicates the macro-I_L event, in which "Preparing the learner for learning" is the instructional action and "Being ready to learn" is the change of learner state. A conceivable process to achieve this is to motivate the learner (Fig. 1 (B)) and then to stimulate recall of prior learning (Fig. 1 (C)). The former instructional action brings about the learner state "Motivated" (Fig. 1 (B)), and the latter does "Recalling prior learning" (Fig. 1 (C)). A way is a description of relationship of such a decomposition of the required change into the detailed changes and actions to achieve them.

A 'Way' has two sorts of interpretations. One, so-called bottom-up manner, is that the sum of the changes of learner state in micro-I_L event promotes the changes of learner state of the macro-I_L event. This manner, which concentrates on states, is descriptive. It describes which outcome is produced by a sequence of changes of learner state. The other, so-called top-down manner, is that an instructional action of a macro-I_L event is decomposed into detailed/concrete instructional actions of micro-I_L events. This manner, which concentrates on action, is prescriptive. It prescribes which sequence of instructional actions is required for performing the intended instructional action.

Following the top-down interpretation, this study proposes a method to systematize theoretical knowledge. The theories prescribe strategies for planning instructional and learning process according to supposed situations. These strategies may superficially vary from theory to theory but, as discussed in the introduction, some of the differences just come from the difference in terminology that each theory uses. We assume that some essentials of theories characterizing themselves are disclosed if their strategies are resolved conceptually. In our framework we propose modeling learning/instructional strategies as Way using L/I/ID ontology. A set of Ways derived from a theory characterizes the theory from the prescriptive aspect. In addition, modeling strategies on a common basis, which is L/I/ID ontology, is expected to disclose not only characteristics of each theory but also commonality among theories.

We call Ways derived from theories 'Way-knowledge'. Such Ways can be applied to various instructional/learning designs if the supposed situation is matched. This study aims to support designers blending theories into their own instructional/learning design by

providing an engineering infrastructure for accumulating and sharing variety of Way-knowledge derived from theories.

2. An example of comprehensive model of educational theories

In our ontological modeling framework for education with the L/I/ID ontology, educational theories are modeled as Way-knowledge. In this section, we will discuss how Way-knowledge describes educational theories comprehensively.

Fig. 2 shows an example of an I_L event decomposition tree. This tree represents a decomposition of the I_L event, "Facilitate learning / Knowledge state". An oval node represents I_L event. Its label expresses combination of instructional action and change of learner state in the form of "instructional action/change of learner state". The links between I_L events found below and above a square represent a Way. I_L events joined to a square and located below it represent an AND relationship. This means that, according to a Way, an upper I_L event is achieved when all of the lower I_L events are achieved. If more than one Way leads to an I_L event, it represents OR relationship among Ways, that is to say, there are more than one method to achieve the change of learner state. This relationship provides alternatives to make more detailed instructional/learning design for designers. Such an I_L event decomposition tree with OR relationship is called "General I_L event decomposition tree".

The general I_L event decomposition tree shown in Fig. 2 covers the whole process of instruction/learning - from preinstruction to assessment -. The foundation of this process is the five major learning components by Dick et al [5]. They are a summary of Gagne's nine events of instruction [7]. These theories are basically considered to be based on cognitivism approach but to be somewhat eclectic in view of paradigms - behaviorism, cognitivism and constructivism - [17]. This model is intended to be a comprehensive model of instructional/learning theories by giving a shape to Dick's components based on various theories in different paradigms.

Now, we take a close look at the decomposition below the I_L event, "Exercise the learner / Absorbed (Fig. 2 (B))", because this decomposition includes both cognitivism and constructivism approaches with OR relationship of Ways. Ways included in this decomposition are based on cognitive approach - Gagne's nine events of instruction [7] and Merrill's component display theory [13] - and constructivist approach - Collins's cognitive apprenticeship [4] and Jonassen's model for designing constructivist learning environments [11] -.

The point of selecting principles from multiple theories is the change of learner state. According to Carey [3] and Ertmer and Newby [6], aspects of constructivist approach can be compatible with aspects of prescriptive approach for specified types of learners and learning outcomes [5]. From this viewpoint, Dick relates constructivist strategy to the five major learning components. In the similar line of these thought, we proposes a modeling method for organizing any theories in terms of what and how their strategies intend to achieve. This study sets up the working hypothesis that the idea of states in the learning process is common while the assumed mechanism of developing knowledge is different for each paradigm[1]. With this consideration, we have organized learner states intended to be shared among different educational theories. "Being ready to learn (Fig.2 (A))" and "Self-aware (Fig.2 (D))" are examples of such learning states. Making attempts to organize common concepts and to interpret (supposed) intention of theories as the change of learner state will afford a better understanding and utilization of educational theories.

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[1] Note that we are not saying all the learning theories share the same learning states.

Let us examine blending of these approaches in more detail. The I_L event "Exercise the learner / Absorbed (Fig. 2 (B))" is decomposed into two sub-I_L events: "Eliciting performance / Absorbed (Fig. 2 (C))" and "Providing informative feedback / Self-aware (Fig. 2 (D))". This decomposition is derived from Gagne's events. To put it briefly in terms of what to be achieved, the former objective is to develop what is learned through practice and the latter one is to become self-aware in order to make the practice more efficient.

These I_L events can be decomposed by both of cognitivist and constructivist approaches. For example, there are two Ways to decompose "Provide informative feedback / Self-aware". Cognitivist approach (Fig. 2 (10)) gives relatively explanatory feedback, e.g. giving correct answer or help. On the other hand, constructivist approach (Fig. 2 (11)) gives relatively inquiring feedback, e.g. providing hint or assisting learners to articulate. Constructivist approach also has other characteristics such as authenticity and self-construction of knowledge, though this is not shown in Fig. 2 because of presenting a contrast to explanatory methods. These characteristics can be described in a more detailed model but are too complicated to explain in detail here.

The key point of the blending of these approaches is, as discussed in the previous section, to take particular note of the change of learner state. These theories indeed have differences in the method. However, at the same time, the objective (intended change of learner state) can be described as common in becoming self-aware in this example. From this viewpoint, we set both the cognitivist and constructivist approaches as a Way to decompose "Providing informative feedback / Self-aware (Fig. 2 (D))". In the same manner as this, other cognitivist and constructivist methods are also organized as Way knowledge shown in Fig. 2 (1) – (13).

3. Toward a theory-aware instructional/learning design support system

One of the remarkable applications of our ontological modeling framework for education is theory-aware design support system for learning contents [8]. By "Theory-aware" [14], we mean the capability of information systems which can support the activities of users based on the understanding of relevant theories.

Nkambou et al. [15] discuss the benefits of accessing theories and required functionalities of theory-aware ITS authoring environment. The benefits are: *1) make decisions (macro, micro) after reflection and reasoning, 2) communicate about or explain their design decisions, 3) check consistency among design decisions, intra-theory and inter-theories, 4) produce scrutable learning environments, 5) have heuristic knowledge grounded in theoretical knowledge.* The required functionalities are that authors can: *1) ask the system what theories apply best to this or that learning situation/goal, 2) ask the system to show examples, 3) ask the system for advice on whether this element of a theory can be combined to an element from another theory, what is the risk associated to doing so, any preferable other solution, etc.*

Referring to their argument, this study focuses on the following two points as the requirement for realization of theory-awareness in an instructional/learning design support system: The system can (1) help designers to build theoretically valid model of learning/instruction, and (2) explain the help with the theoretical justification to designers. We now discuss how our ontological modeling framework for education contributes to these two advantages.

As discussed in the previous sections, learning/instructional strategies included in educational theories are described as Way-knowledge in our modeling framework. Way-knowledge is a relationship between macro-I_L event and some micro ones with desired change of learner state (goal) and necessary condition for the change (situation). In

addition, Way-knowledge is described with not each theory's own terminology but our L/I/ID ontology. This ontology is designed to accept terminological difference among educational theories and paradigms on a conceptual level as mentioned before. Based on this ontology, Way-knowledge is not only human-readable but also machine-readable. This enables systems to expound educational theories described as Way-knowledge and to interpret models of learning/instruction built by learning/ instructional designers founded on educational theories. These will be quite helpful to learning/instructional designers for in-depth understanding of theories and for communicating about their design decisions and products.

Another characteristic of our modeling framework is that a theory is described as a set of Way-knowledge. In other words, a theory is split into pieces of strategy and each strategy is described as a Way-knowledge. For example, in fig. 2, Way-knowledge (1), (2), (4), and (6) is derived from Gagne and Briggs's theory, and (8) and (12) derives from Merrill's component display theory. Such modeling of theories helps learning/instructional designers to make a model of learning/instruction from various viewpoints such as those that follow. One viewpoint is that a support system can pick and choose applicable strategies within a theory according to the grain size of process. If a designer wants to decompose complete learning/instructional process by him/herself, Way knowledge (1) is recommended. On the other hand, if he/she wants to do more detailed process, Way knowledge (4) or (6) are recommended.

The other is that a support system can also suggest whether an element of a process derived from a theory can be exchanged by an element derived from another theory. Way-knowledge (10) and (11) illustrated below the I_L event "Provide informative feedback /Self-aware (Fig. 2 (D))" is a good example to illustrate the possibility of exchange. Such guidance becomes possible with inter-theory comparison in terms of strategies included in theories or derived from them.

4. Conclusion

We have discussed a modeling framework for learning/instructional design based on ontological engineering. The characteristics of this framework include: 1) a theory/ paradigm-independent ontology for modeling learning/instruction, 2) compatibility between prescriptive and descriptive models derived from educational theories, 3) theory-awareness brought out by an ontological modeling framework.

In this paper, we have concentrated on how the theory/paradigm-independent ontology contributes to modeling learning/instruction from a comprehensive viewpoint of various educational theories. Our modeling framework based on this ontology will be helpful to blend of educational theories as discussed in section 2, and to enhance the quality of support by information systems for learning/instructional design as discussed in section 3.

The following issues to be examined further still remain: 1) investigating the theory/paradigm-independence of the L/I/ID ontology through organizing much more educational theories in our modeling framework, 2) considering the relation between learning objects and abstract design of learning contents described as an I_L event decomposition tree, 3) implementation of a theory-aware design support system for learning contents, and 4) compliance with standards for semantic web and e-learning.

Acknowledgments

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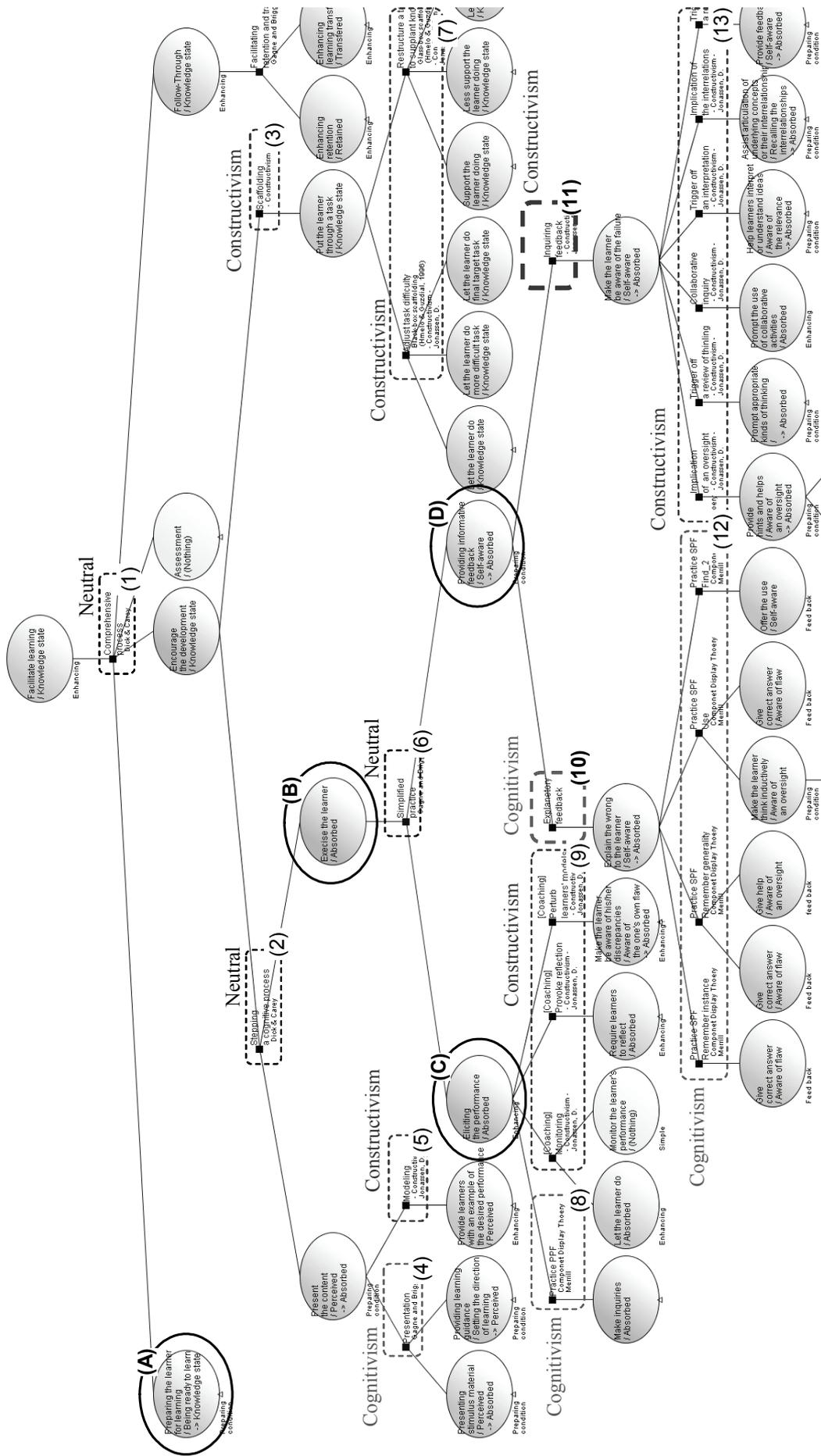
Fig. 2 A general function decomposition tree